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COMPUTING OPTIMUM HEIGHTS for BALLOON-BORNE RADAR

by

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13. Abstract: The Air Defense Initiative is considering the use of balloon-borne radar transmitters. Tethering the balloon at an optimum height based on atmospheric refractive effects maximizes the chances for effective target detection. This report provides information for determining optimum transmitter heights for balloon-borne radars by considering the effects of atmospheric refraction. The data is provided on a floppy disk as tables of radar detection data stratified by transmitter and target heights. The tables are accessible through a user-friendly interactive PC program that displays the data. Instructions for access to and interpretation of the tables are included. The report summarizes the assumptions, data, and methods used to create the tables.

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PREFACE

This report documents work done on USAFETAC Project 90124600 for the Electronics Systems Division (ESD/XRTI). The purpose of the project was to provide system planners with information for determining optimum transmitter heights for balloon-borne radars used in the Air Defense Initiative. Using the effects of atmospheric refraction to select an optimum height for the radar transmitter allows users to maximize target detection effectiveness. Project analyst was Mr Michael Squires, USAFETAC/SYT.

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INTRODUCTION

The purpose of USAFETAC Project 90124600 was to provide Electronic Systems Division (ESD/XRTI) planners with a way to use the effects of atmospheric refraction to determine optimum transmitter heights for balloon-borne radars and maximize target detection efficiency.

Radars are designed with the assumption of a "standard atmosphere," which essentially represents a worldwide, all-season, climatological profile of pressure, temperature, and moisture as a function of height. Given this profile, a radar beam is expected to refract in a given way at a given altitude. Every combination of range and elevation angle, then, yields a unique radar beam height. "Standard atmospheric" conditions, however, are seldom, if ever, found in nature. This study uses site-specific climatology to provide a better, more realistic "atmosphere" and the associated refractive effects at specific locations.

Certain types of atmospheric profiles cause "anomalous" refraction of radar beams. In this context, "anomalous" does not mean "rare event"; it simply means that the refraction is *different* from that in the standard atmosphere. Anomalous refraction can occur a significant amount of time in some regions of the world. Locations that have a high incidence of inversions, for example, also have a high incidence of anomalous refraction (Farrell, 1988).

As an example, very stable layers in which atmospheric moisture decreases rapidly with height (as in radiation and subsidence inversions) cause the radar beam to be refracted abnormally downward. In some cases, the beam hits the ground. Extended detection ranges may result. Conversely, if the atmosphere is extremely *unstable*, the radar can be refracted abnormally upward, *decreasing* the detection range.

Anomalous refraction also causes "height error," or the difference between the indicated altitude of a target on radar and its actual height in the atmosphere. If the beam is refracted abnormally downward, the beam will detect targets at lower altitudes than expected. The radar display, however, which uses the standard atmosphere as a reference, indicates that the target is at a higher altitude. Under certain atmospheric conditions, the height error can be thousands of meters (Squires, 1991).

Most of the atmospheric profiles that cause anomalous propagation are found at lower altitudes. The radar beam will be refracted abnormally only if the beam is at a shallow elevation angle (usually less than a few degrees from horizontal). Therefore, one way to mitigate the anomalous effects of atmospheric refraction is to raise the radar transmitter on a tethered balloon so that it is above the atmospheric discontinuity that causes anomalous refraction. If the transmitter is high enough, the radar antenna would be pointing down at a large enough angle to minimize refraction effects.

The primary reason for increasing transmitter height, of course, is to increase the radar horizon, or the range at which low-flying targets can be detected. There are several things to consider when deciding how high to tether the radar transmitter. For example, sometimes the atmospheric discontinuity causing anomalous propagation occurs at higher elevations; this is especially true in

the case of subsidence inversions. Raising the radar in this case could actually *enhance* anomalous refraction.

Another consideration is elevation angle. At longer ranges, the radar beam still penetrates the atmosphere at shallow elevation angles. The higher the radar transmitter is tethered, the greater the distance at which shallow elevation angles will occur.

There are also engineering considerations. For example, "ground-clutter" can cause problems. And of course there are practical limitations to the height at which a radar transmitter can be tethered.

System planners can use this report and the tables provided separately on floppy disk to examine trade-offs between different balloon heights and the limitations imposed by the atmosphere.

Because of the large amount of information to be provided, the data discussed in this report is compressed and stored on one 5 1/4-inch diskette (included). A user-friendly PC program displays the data in tabular form. An IBM-compatible PC with MS-DOS 5.0 or higher is required.

To install and run the program:

1. Create a subdirectory on your hard drive.

2. Copy the file ADI.EXE to your new subdirectory from the diskette.

3. Enter the subdirectory and type "ADI." This will uncompress the data.

4. To start the program, type "ADISEL20."

5. The program will ask you for inputs that will display the tables you've selected using the DOS editor. You may browse or print a table.

6. To exit, enter the "FILE" menu and select "EXIT." The program will ask your if you want to view another table. If you say "YES" you'll be prompted for more inputs. If you say "NO," the program will terminate.

7. A printing note: The tables are 130 characters across. If this is a problem for your printer, save the table as a DOS text file. Import this file into a word-processing program, change the font to 16 1/2 CPI, and make the margins as small as possible. This will let the table fit on one page. Note, however, that tables for higher transmitter heights are several pages long.

DATA AND ASSUMPTIONS

The radar and radiosonde (RAOB) stations used in this study are shown in Table 1. The information in this report is based on weather data collected at the RAOB sites, which were, in effect, substituted for the nearby radar site. Distances between radar and RAOB sites, as well as the height of the sites above mean sea level (MSL) is also given. All RAOB data used in this study was from USAFETAC's upper-air database. Height, temperature, pressure, and vapor-pressure data for each station was used to compute modified refractivity at each level. Gross error checks were performed on all data. A 10-year period of record (POR) was used for each station.

Table 1. Radar and Radiosonde Sites

Radar Location	Radiosonde Site	Distance (NM)
Mill Valley, CA (2,650 feet MSL)	Oakland, CA (20 feet MSL)	21
Makah, WA (1,463 feet MSL)	Quillayute, WA (203 feet MSL)	25
Mt Laguna, CA (1,890 feet MSL)	San Diego, CA (30 feet MSL)	38

A raytrace model (CLIMORAY, Squires, 1991), was used to calculate the path of the radar beam through the atmosphere. The CLIMORAY model uses geometric optics (Snell's Law) to perform its calculations. The RAOB data is used as input to CLIMORAY. We did not have "error bars" for the CLIMORAY output, but we plan to study the effect of random and systematic errors of temperature and moisture measurements on raytrace calculations. CLIMORAY has, however, been verified against other raytrace models (IREPS; EREPS) that are considered accurate. The refractivity profile specified by the RAOB data is assumed to be representative of the environment along the entire radar path. Because of the spacing of RAOB sites (typically every 300 NM), there is no other way to deal with this problem.

Another assumption deals with the manner in which a target is determined to be detected or not detected. If the radar beam is *below* a target, "detection" is assumed. If the radar beam is *above* the target, the target is considered "not detected."

In cases of extreme ducting, a "radar hole" could develop. Although the radar beam may be *below* the target, it still would not be detected. However, if the beam were *above* a target in a radar hole, non-detection would be assumed.

METHOD

Table 2 gives the radar transmitter heights and target heights specified by the customer. The eight transmitter heights and four target heights result in 32 combinations. Each transmitter height versus target height combination represents a data file on the floppy disk and a separate table–see Table 3.

Table 2. Transmitter and Target Heights

TRANSMITTER HEIGHT (feet MSL)	TARGET HEIGHT (feet MSL)
SURFACE	150
500	500
1000	1000
2000	3000
4000	
6000	
8000	
10000	

CLIMORAY was run at 25-NM increments out to 200 NM for each RAOB at each of these transmitter-target height combinations, At each 25-NM increment, it was determined if the radar beam hit the ground, detected the target, or was *above* the target. This process was carried out over a domain of elevation angles that included all the cases of detection. The domain of elevation angles varies with the specific transmitter-target height combination. The next section explains how the domain of elevation angles is actually chosen. This process was used for the entire POR.

A statistical analysis was performed for the data associated with the current transmitter-target height combination. Probability of detection statistics (beam hit the ground, detection, non-detection) for each angle-range increment combination was computed. All the computed probabilities associated with a particular transmitter-target height combination make up one table. After this process had been repeated for each of the 32 transmitter-target height combinations, the 32 resulting tables were downloaded into separate PC files.

A single table can be viewed on an IBM-compatible PC by using the ADISEL20 program distributed with the data. ADISEL20 is interactive and user-friendly. When the user enters station name, transmitter height, and target height in response to a prompt, the appropriate table is displayed. Users may call up other tables or exit the program. Tables can be printed.

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TABLE 3. Example table from PC program ADISEL20.

PERCENT OF TIME A TARGET IS DETECTED
TRANSMITTER HEIGHT - 1000 FT MSL
MILL VALLEY, CA (OAKLAND RAOB DATA)

TARGET HEIGHT (FT MSL) = 500

	RANGE (NM)																							
	25			50			75			100			125			150			175			200		
	DETECTION			DETECTION			DETECTION			DETECTION			DETECTION			DETECTION			DETECTION			DETECTION		
ANGLE	GND	YES	NO	GND	YES	NO	GND	YES	NO	GND	YES	NO	GND	YES	NO	GND	YES	NO	GND	YES	NO	GND	YES	NO
-0.70	100	0	0	100	0	0	100	.	0	100	.	0	100	.	0	100	.	0	100	.	0	100	.	0
-0.65	100	0	0	100	0	0	100	.	0	100	.	0	100	.	0	100	.	0	100	.	0	100	.	0
-0.60	99	1	0	99	0	1	99	.	1	99	.	1	99	.	1	99	.	1	99	.	1	99	.	1
-0.55	89	11	0	98	1	1	98	0	2	98	.	2	98	.	2	98	.	2	98	.	2	98	.	2
-0.50	19*	81	0	76	20	3	76	0	24	76	.	24	76	.	24	76	.	24	76	.	24	76	.	24
-0.45	6*	94	0	30*	58	12	30	3	66	30	0	69	30	0	70	30	0	70	30	.	70	30	0	70
-0.40	2*	98	1	12*	36	52	13	3	84	13	0	87	13	0	87	13	0	87	13	0	87	13	0	87
-0.35	0*	69	31	5	15	80	6	2	93	6	0	94	6	0	94	6	0	94	6	0	94	6	0	94
-0.30	0	14	85	3	7	90	3	1	96	3	0	97	3	0	97	3	0	97	3	0	97	3	0	97
-0.25	0	6	94	1	5	94	1	1	98	2	0	98	2	0	98	2	0	98	2	0	98	2	0	98
-0.20	0	2	98	1	3	96	1	1	98	1	0	99	1	0	99	1	0	99	1	0	99	1	0	99
-0.15	0	1	99	0	2	98	0	1	99	0	0	99	0	0	99	0	0	100	0	0	99	0	0	99
-0.10	0	0	100	0	1	99	0	1	99	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100
-0.05	0	0	100	0	1	99	0	0	99	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100
0.00	0	0	100	0	0	99	0	0	99	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100
0.05	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100

GND = BEAM HIT GROUND YES = TARGET DETECTED NO = TARGET NOT DETECTED
* INDICATES DETECTION IN THE STANDARD ATMOSPHERE.

INTERPRETING THE RESULTS

An example of the tables provided on disk is given in Table 3, opposite. Displaying these tables, each associated with a particular transmitter-target height combination, was explained in the previous section.

At each elevation angle-range intersection in these tables, three percentages are given; they represent (1) GND--the percent of time the radar beam hit the ground, (2) YES--the percent of time the radar beam was below the target (detection), and (3) NO--the percent of time the radar beam was above the target (non-detection). The second case can be considered as the "probability of detection," or POD.

The example table gives detection probabilities for a transmitter height of 1,000 feet MSL and a target height of 500 feet MSL for Mill Valley, CA. The asterisks in the "YES" column indicate detection in the standard atmosphere. At 50 NM and -0.45 degrees elevation angle, the table indicates the following:

- the radar beam hits the ground 30 percent of the time,
- the target is detected 58 percent of the time (POD = 58 percent),
- the target is *not* detected 12 percent of the time, and
- the standard atmosphere implies (erroneously) that the target would be detected 100% of the time.

As shown in Table 3, certain patterns are evident in all the tables. At the lowest elevation angles, the radar beam is hitting the ground 100 percent of the time at all ranges. At successively higher elevation angles, the percentages begin to transition from 100 percent in the "GND" column, through the "YES" column, until the "NO" column is filled with 100 percent at all ranges. This is the domain of elevation angles discussed earlier. Notice that, as shown in Table 3, it is not necessary for the POD to reach 100 percent.

Some elevation angle-range combinations indicate that the radar beam hits the ground some percent of time and is above the target the rest of the time. The POD is zero. Physically, this represents geometries (transmitter-target-angle-rangecombinations) in which the target is always below the radar horizon.

For example, in Table 3 at an elevation angle of - 0.35 degrees and a range of 100 NM, the radar beam hits the ground 6 percent of the time and is above the target 94 percent of the time. This distribution repeats itself at 125, 150, 175, and 200 NM. This is because the radar beam always hits the ground at or before 100 NM. Therefore, on successive runs of CLIMORAY at longer ranges, the distribution remains the same.

Another use for the tables is to compare the detection specified by the standard atmosphere with the POD specified by the climatology for a specific site. An asterisk in the "YES" column indicates detection within the standard atmosphere; this is usually associated with a high probability of detection, but not always. Frequently, the standard atmosphere indicates no detection, and climatology specifies some probability of detection.

Note that much of the value associated with these tables lies in the direct comparison between the standard atmosphere prediction and the climatological prediction. For example, in Table 3, the probability of detection at 25 NM ranges from 69 to 98 percent at elevation angles where the standard atmosphere indicates detection. At 50 NM, the probability of detection only ranges from 36 to 58 percent. Put another way, with a transmitter height of 1,000 feet MSL, an elevation angle of -0.40 degrees, and a range of 50 NM, a target at a height of 500 feet would be detected according to the standard atmosphere. However, climatology (which is closer to reality) indicates that the target will be detected only 36 percent of the time.

The tables also allow users to set up criteria for variables such as target and transmitter heights and minimum probability of detection, then determine at what range these criteria would be met. For example, if the transmitter height is 1,000 feet MSL, the target is at 500 feet MSL, and a probability of detection of at least 90 percent is desired, at what range could detection be expected? According to Table 3, the answer would be about 25 NM. The standard atmosphere, however, implies that detection would occur at 50 NM.

Many other criteria could be established, such as critical range and POD for a target at a given altitude. The tables could then be searched for a transmitter height that would meet those criteria, providing answers to these kinds of "what if" questions.

SUMMARY

The purpose of this project was to provide system planners a way to determine optimum heights for balloon-borne radar transmitters in order to maximize target detection. To provide this information, tables of radar detection data stratified by transmitter and target heights were created.

This report summarizes the assumptions, data, and methods used to create the tables, which are accessible on floppy disk through a user-friendly interactive PC program provided with the report. Instructions for using the tables are also provided.

PROGRAM DISK

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